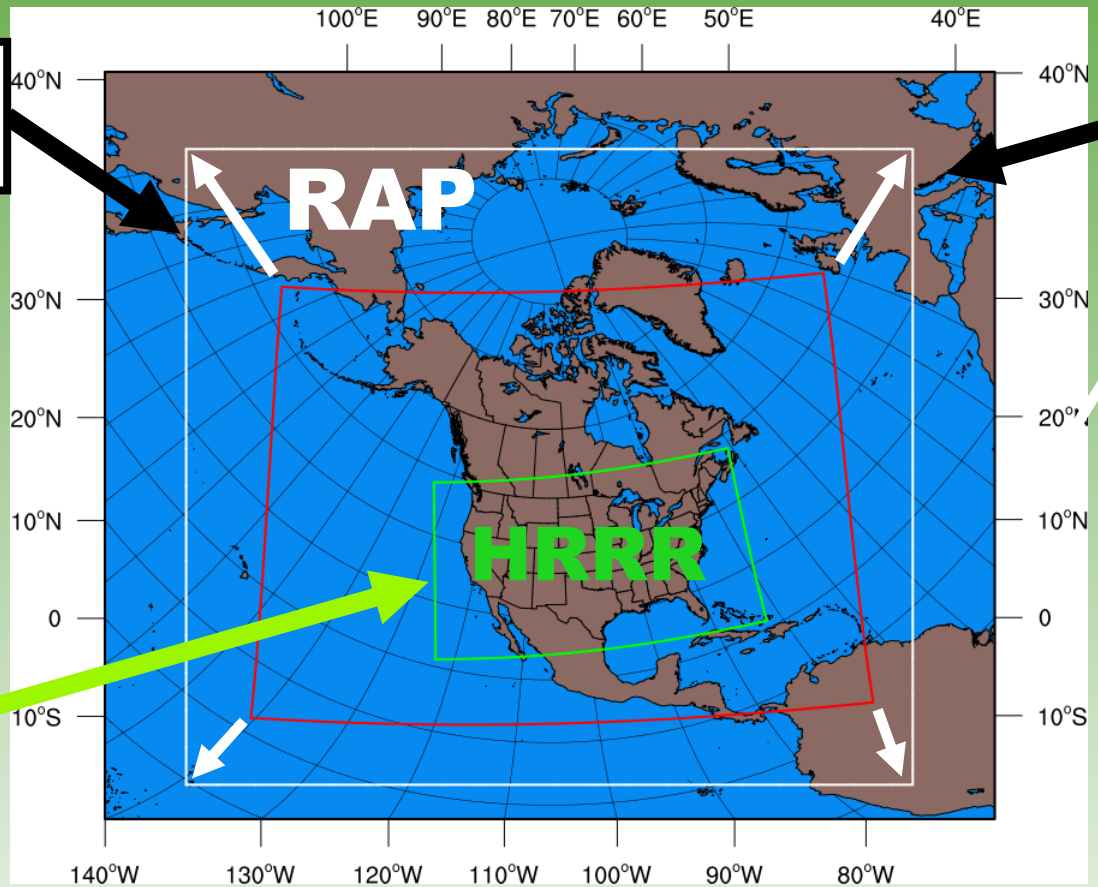
RAP/HRRR: Hourly-Updating Weather Forecast Models

13-km Rapid Refresh (RAPv3) – to 21h (May 2016)

Initial & Lateral Boundary Conditions

3-km High-Resolution Rapid Refresh (HRRRv2) – to 18h (May 2016)



Expanded RAP to match NAM for SREF

(May 2016)

RAP coverage of Hawaii

RAP/HRRR Implementation History

Operational Implementations

01 May 2012
- **RAPv1**: Adoption of GSI, WRF-ARW and unified post
- Enabled use of community-developed software

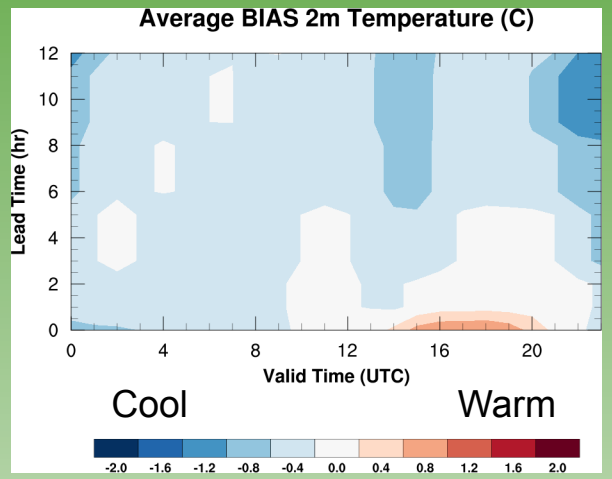
25 Feb 2014
- **RAPv2**: Hybrid EnKF-3DVar data assimilation
- Significant improvement in upper-air forecasts

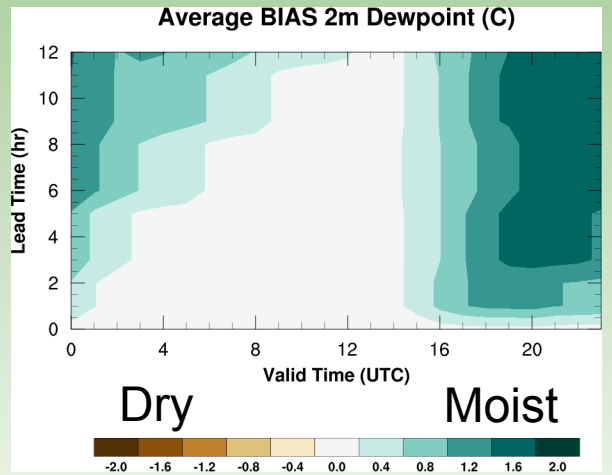
30 Sep 2014
- **HRRRv1**: 3-km Radar DA in WRF-ARW
- Significant improvement in convective forecasts

12 May 2016
- **RAPv3/HRRRv2**: Aerosol Thompson MP, improvements to
- MYNN PBL, RUC LSM, RRTMG Rad, Grell-Freitas cumulus
- Significant improvement in surface forecasts

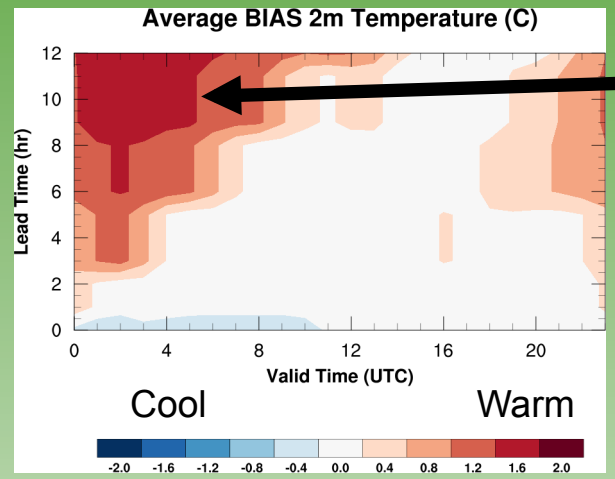
Operational RAPv2/HRRRv1 Forecast Biases

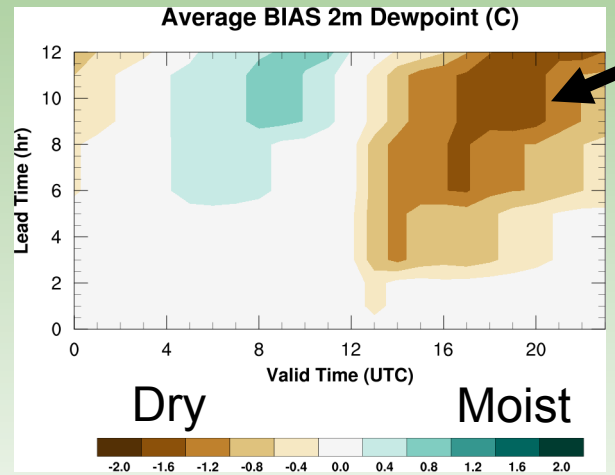
Winter (Jan-Mar)





Summer (Jul-Sep)



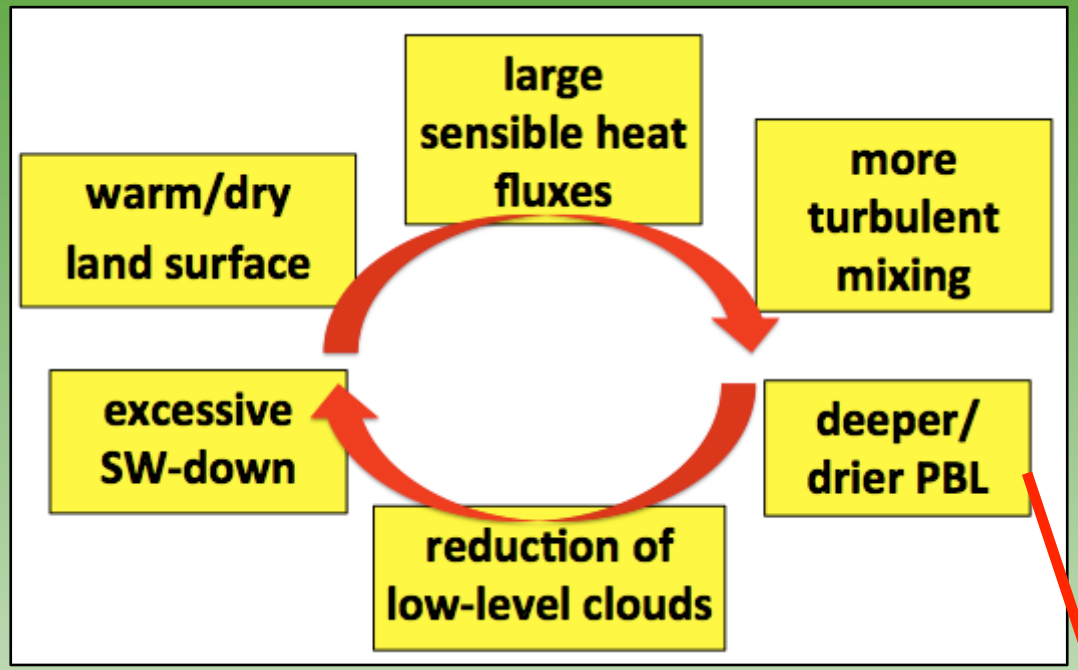


The RAP/HRRR has a daytime warm bias in the warm season.

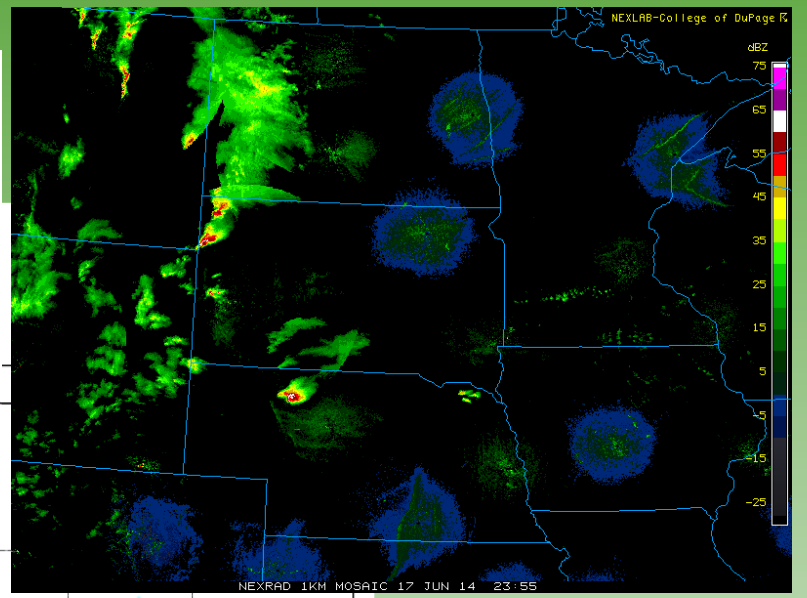
The RAP/HRRR has a daytime dry bias in the warm season.

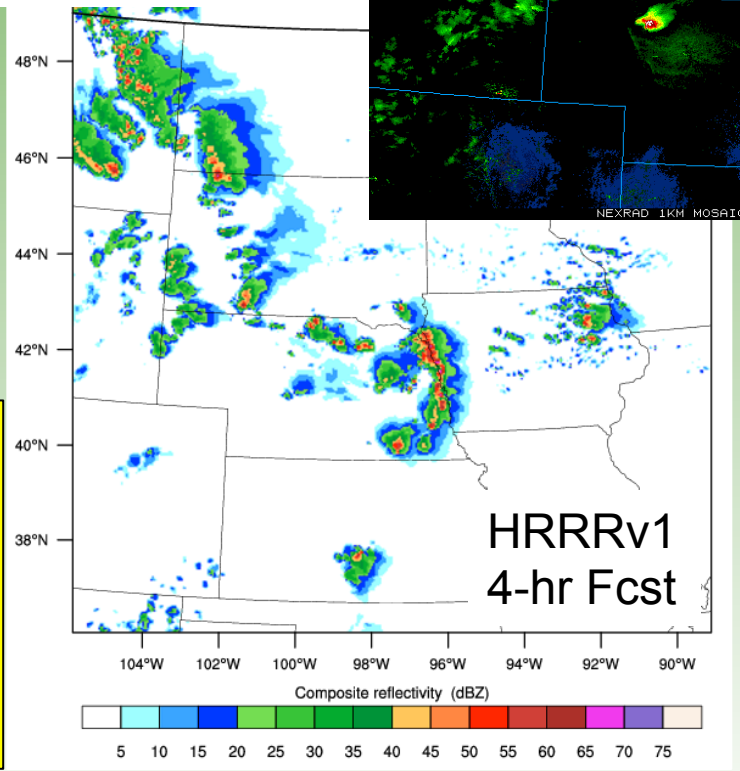
Experimental improvements to the model to remove bias have been made and will be implemented in RAPv3/HRRRv2.

Operational RAPv2/HRRRv1 Bias Conceptual Model



00 UTC
18 June 2014
Coleridge, NE



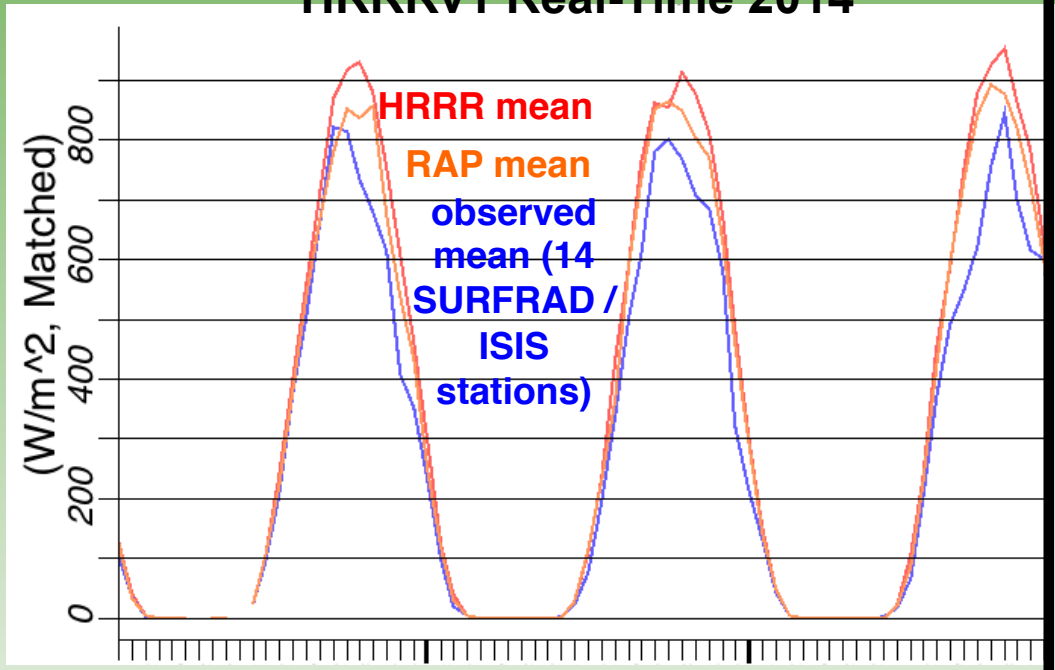


Led to occasional spurious high-based convective initiation in more weakly-forced diurnally-driven events

HRRRv2 Real-Time Case Study: Spring Radiation

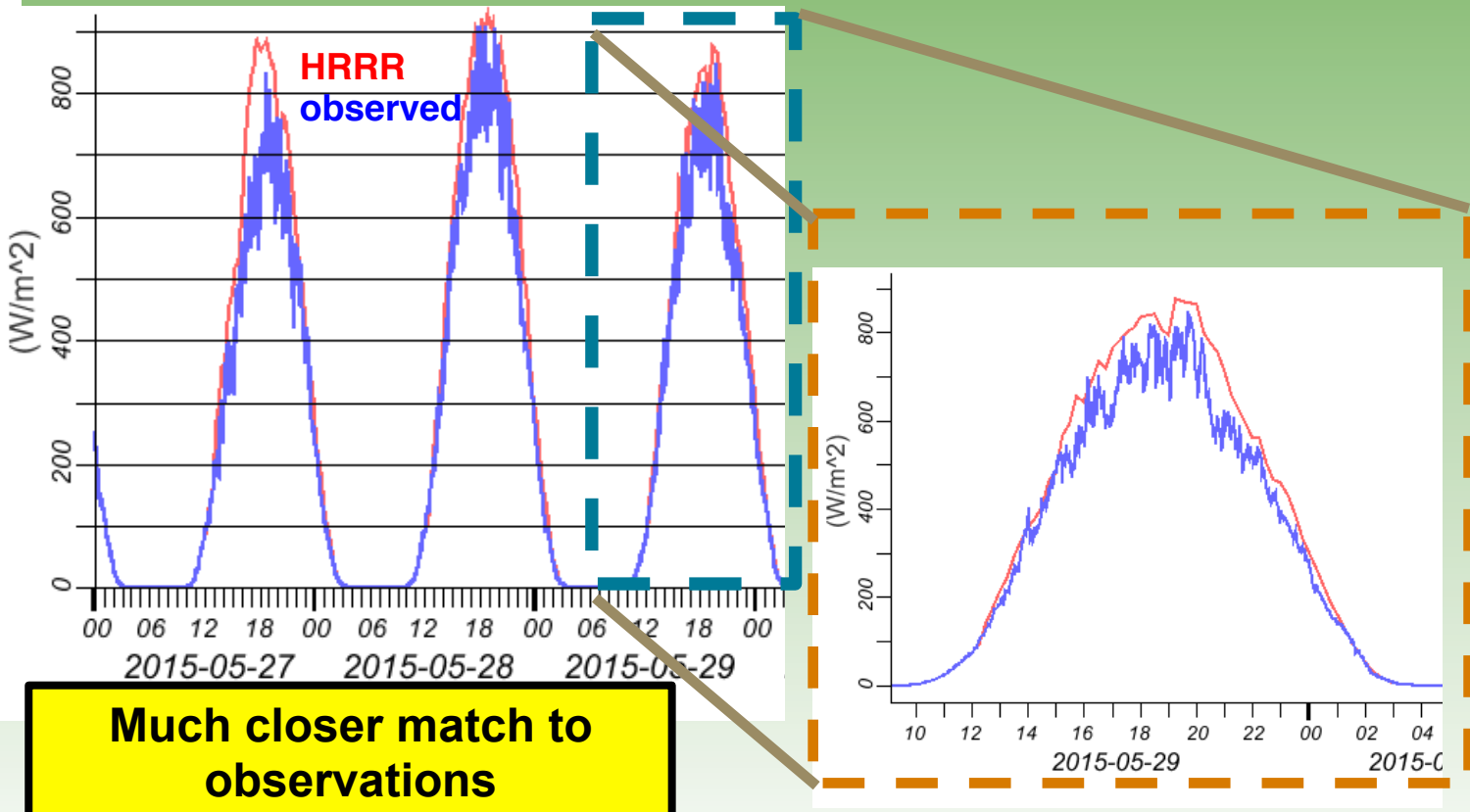
Downward Shortwave Flux at Surface
12-hr Forecasts

HRRRv1 Real-Time 2014



Average excess of ~ 80-100 W/m² incoming shortwave radiation

HRRRv2 Real-Time 2015



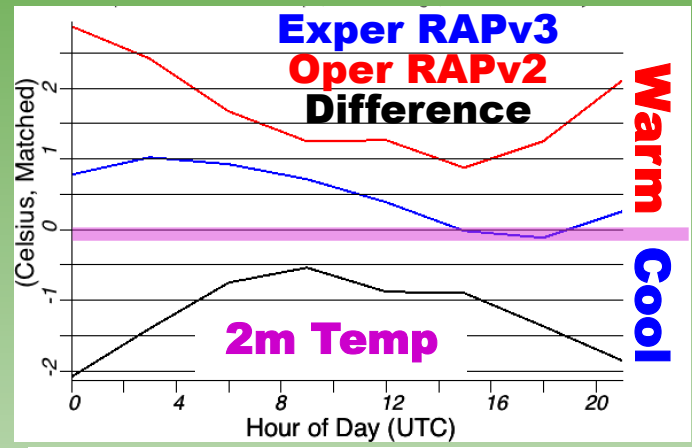
Much closer match to observations

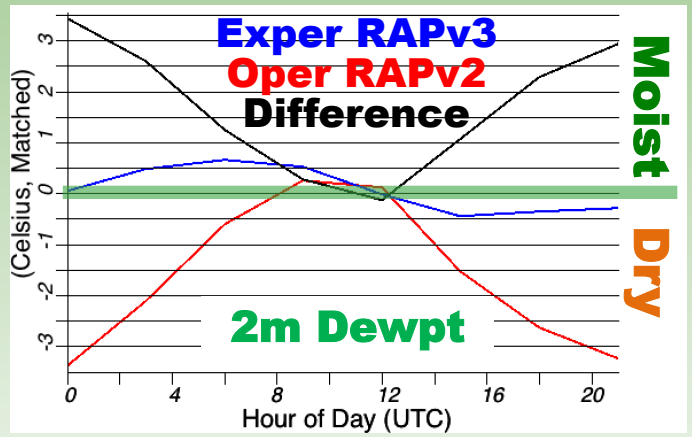
RAPv3/HRRRv2 Model Forecast Improvements

HRRR component improvements to address warm/dry bias in RAPV2/HRRRv3

Component	Mitigating Items
GSI Data Assimilation	Canopy water cycling Temp pseudo-innovations thru model boundary layer More consistent use of surface temp/dewpoint data
GFO Convective Parameterization	Shallow cumulus radiation attenuation Improved retention of stratification atop mixed layer
Thompson Microphysics	Aerosol awareness for resolved cloud production Attenuation of shortwave radiation
MYNN Boundary Layer	Mixing length parameter changed Thermal roughness in surface layer changed Coupling boundary layer clouds to RRTMG radiation
RUC Land Surface Model	Reduced wilting point for more transpiration Keep soil moisture in croplands above wilting point

Reduced warm / dry bias





RAPv3/HRRRv2 Observation Data Assimilation Changes

New in RAPv3/HRRRv2

Radial Velocity (RAPv3)
Lightning (RAPv3)
Mesonet (RAPv3/HRRRv2)
RARS Radiances (RAPv3)

Hourly Observation Type	Variables Observed	Observation Count
Rawinsonde	Temperature, Humidity, Wind, Pressure	120
Profiler – 915 MHz	Wind, Virtual Temperature	20-30
Radar – VAD	Wind	125
Radar	**Radial Velocity**	**125 radars**
Radar reflectivity – CONUS	3-d refl ➔Rain, Snow, Graupel	1,500,000
Lightning	**(proxy reflectivity)**	**NLDN**
Aircraft	Wind, Temperature	2,000 -15,000
Aircraft - WVSS	Humidity	0 - 800
Surface/METAR	Temperature, Moisture, Wind, Pressure, Clouds, Visibility, Weather	2200 - 2500
Surface/Mesonet	**Temperature, Moisture, Wind**	**~5K-12K**
Buoys/ships	Wind, Pressure	200 - 400
GOES AMVs	Wind	2000 - 4000
AMSU/HIRS/MHS **(RARS)**	Radiances	1K-10K
GOES	**Radiances**	**large**
GOES cloud-top press/temp	Cloud Top Height	100,000
GPS – Precipitable water	Humidity	260
WindSat Scatterometer	Winds	2,000 – 10,000

RAPv3/HRRRv2 Summary of Changes

Operational RAPv2/HRRRv1

Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Pressure Top	Boundary Conditions	Initialized
RAP	GSD, NCO	North America	758 x 567	13 km	50	10 mb	GFS	Hourly (cycled)
HRRR	GSD, NCO	CONUS	1799 x 1059	3 km	50	20 mb	RAP	Hourly (pre-forecast hour cycle)

Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.4.1+	GSI Hybrid 3D-VAR/Ensemble	13-km DFI	RRTM/ Goddard	Thompson v3.4.1	G3 + Shallow	MYNN	RUC
HRRR	WRF-ARW v3.4.1+	GSI 3D-VAR	3-km 15-min LH	RRTM/ Goddard	Thompson v3.4.1	None	MYNN	RUC

Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	6th Order Diffusion	SW Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	$5^{th}/5^{th}$	Positive-Definite	w-Rayleigh 0.2	Yes 0.12	10 min	MODIS Fractional	0.01 K/s	60 s
HRRR	$5^{th}/5^{th}$	Positive-Definite	w-Rayleigh 0.2	No	5 min	MODIS Fractional	0.07 K/s	20 s

RAPv3/HRRRv2 Summary of Changes

Implementation RAPv3/HRRRv2

Larger RAP Domain

Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Pressure Top	Boundary Conditions	Initialized
RAP	GSD, NCO	North America	953 x 834	13 km	50	10 mb	GFS	Hourly (cycled)
HRRR	GSD, NCO	CONUS	1799 x 1059	3 km	50	20 mb	RAP	Hourly (pre-forecast hour cycle)

Newer Model Version
More Ensemble Weight
Advanced Physics

Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.6+	GSI Hybrid Ensemble to 0.75	13-km DFI	RRTMG/ RRTMG	Thompson Aerosol v3.6	GF + Shallow	MYNN v3.6	RUC v3.6
HRRR	WRF-ARW v3.6+	GSI Hybrid Ensemble to 0.75	3-km 15-min LH	RRTMG/ RRTMG	Thompson Aerosol v3.6	None	MYNN v3.6	RUC v3.6

Seasonal Vegetation Fraction/Leaf Area Index

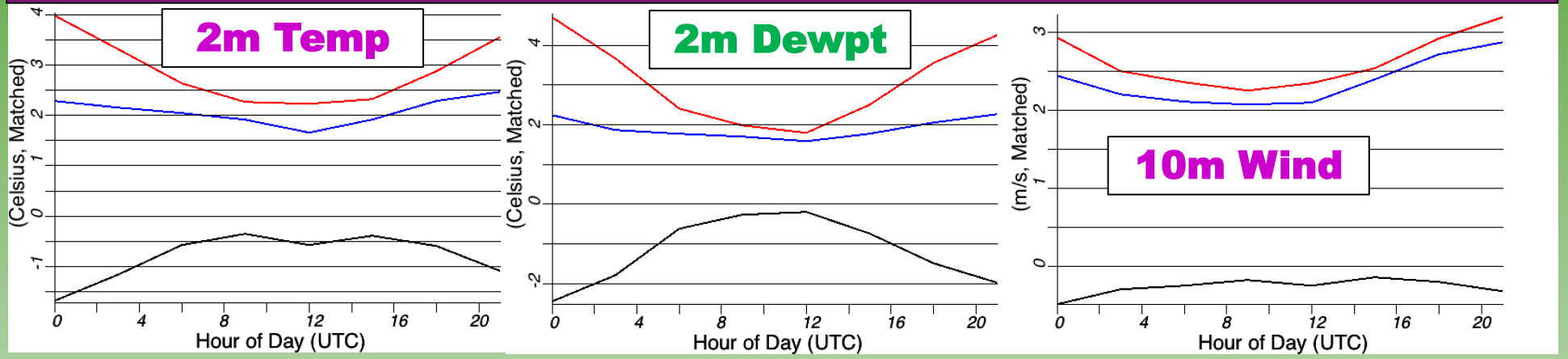
Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	6th Order Diffusion	SW Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	$5^{th}/5^{th}$	Positive-Definite	w-Rayleigh 0.2	Yes 0.12	20 min	MODIS Seasonal	0.01 K/s	60 s
HRRR	$5^{th}/5^{th}$	Positive-Definite	w-Rayleigh 0.2	Yes 0.25 (flat terr)	15 min with SW-dt	MODIS Seasonal	0.07 K/s	20 s

RAPv3 Retrospective Tests: Surface

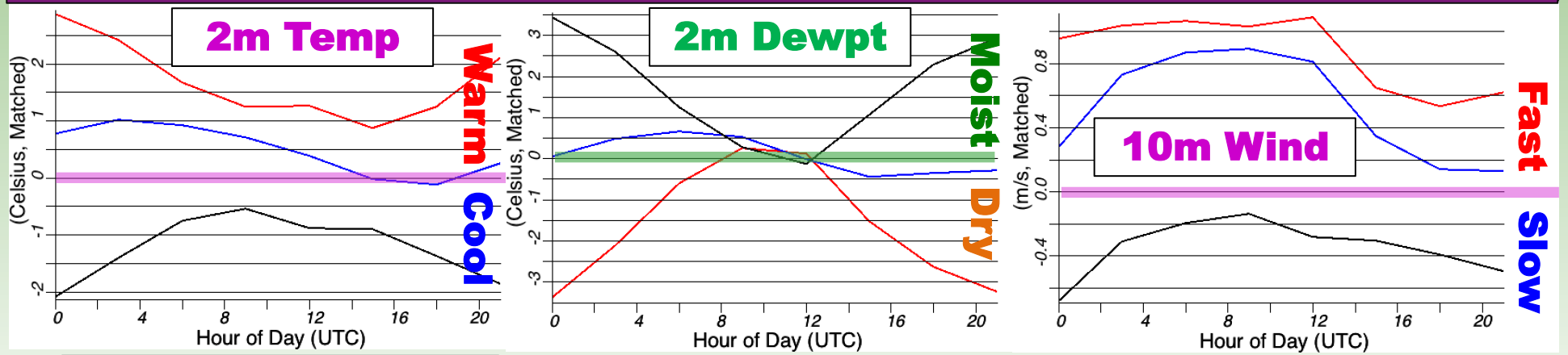
Eastern US
15 Jul – 15 Aug 2014

Exper RAPv3
Oper RAPv2
RAPv3 - RAPv2 Difference

RAP Surface 12-hr Forecast RMSE



RAP Surface 12-hr Forecast Bias



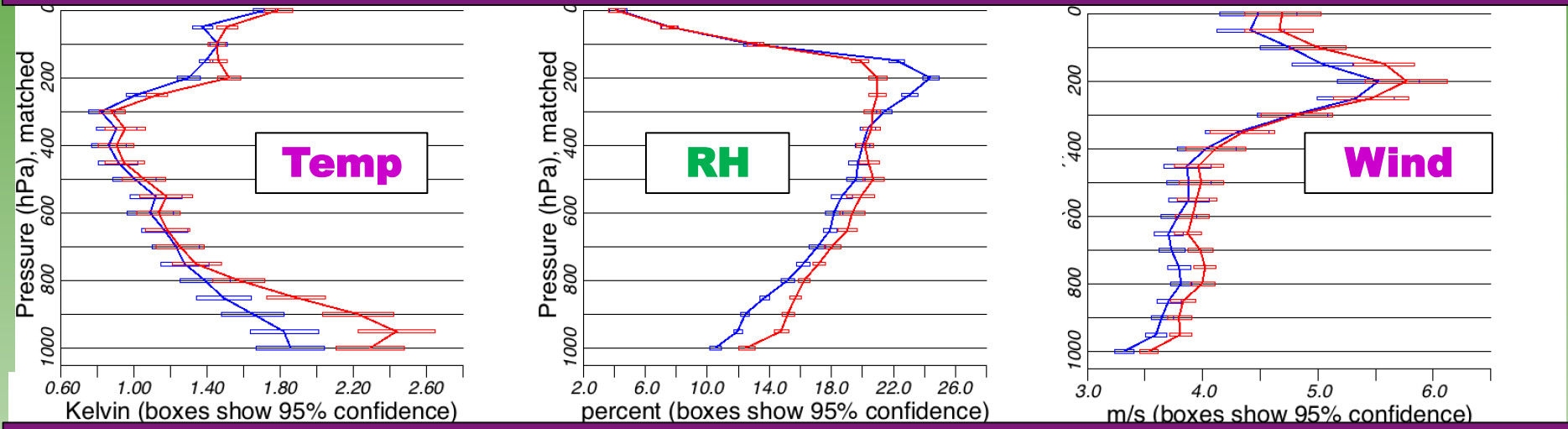
Reduced warm bias | **Reduced dry bias** | **Reduced fast bias**

RAPv3 Retrospective Tests: Upper-Air

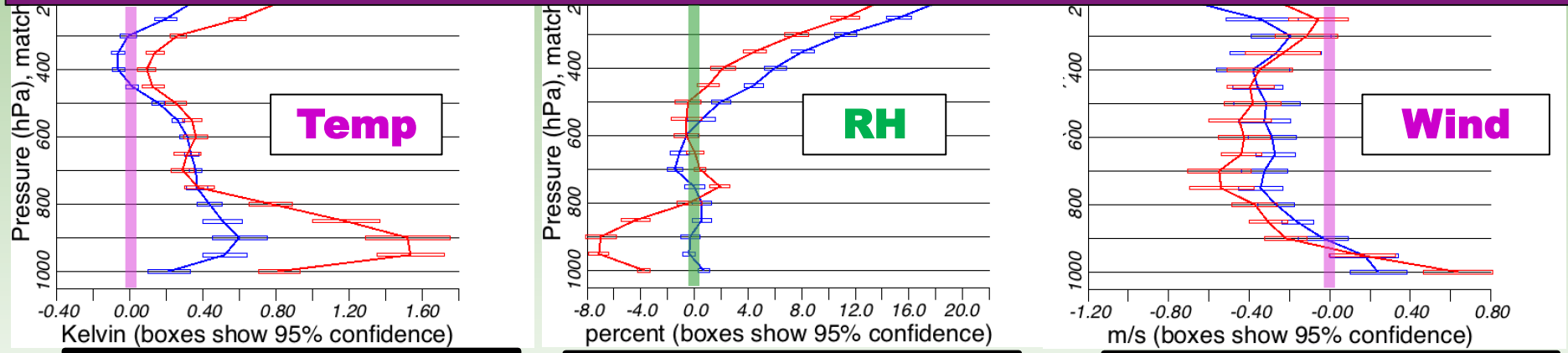
Eastern US
15 Jul – 15 Aug 2014

Exper RAPv3
Oper RAPv2
RAPv3 - RAPv2 Difference

RAP Upper-Air 12-hr Forecast RMSE



RAP Upper-Air 12-hr Forecast BIAS (00 UTC Only)



Reduced warm bias

Reduced dry bias

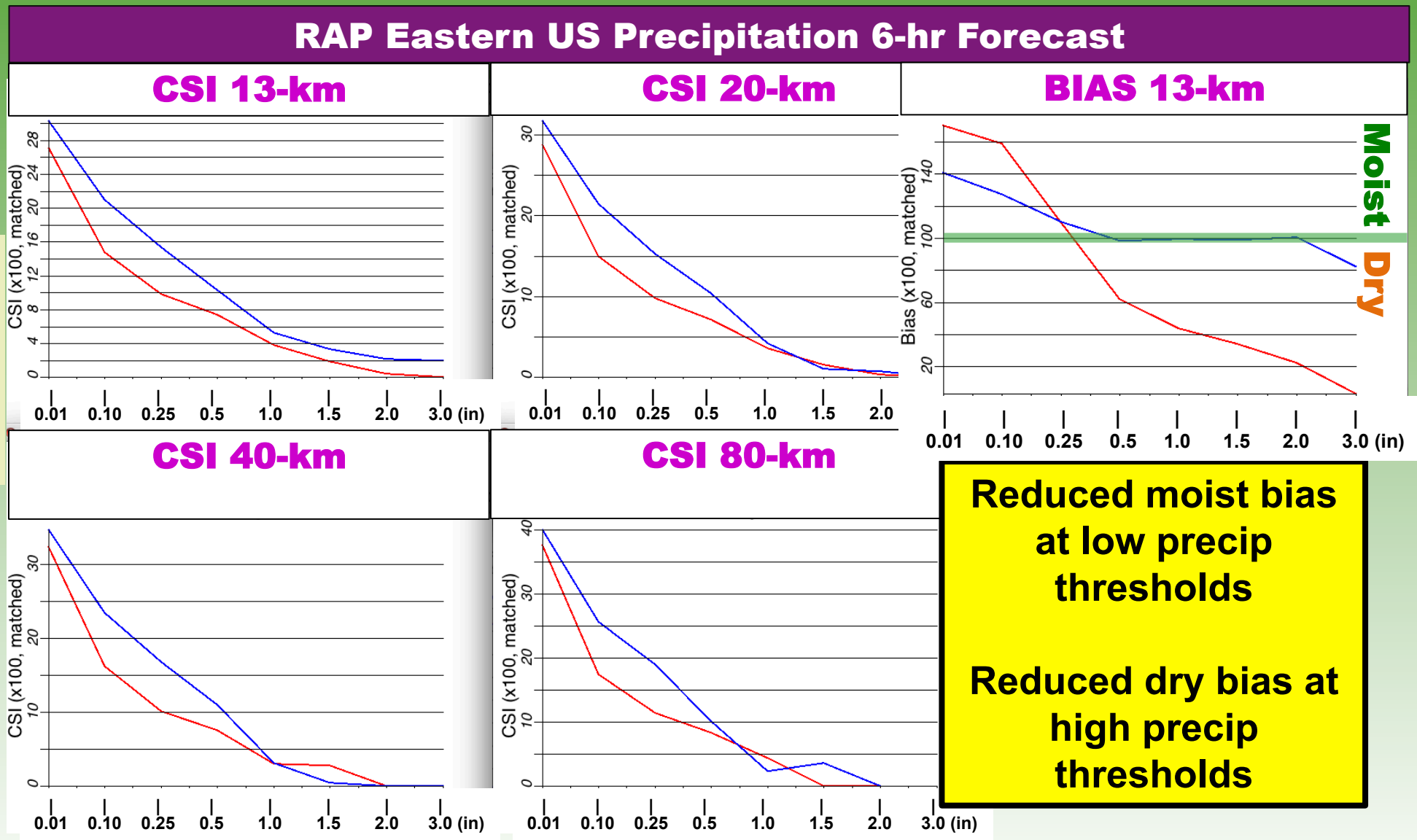
Reduced fast bias

RAPv3 Retrospective Tests: Precipitation

Eastern US
15 Jul – 15 Aug 2014

Exper RAPv3
Oper RAPv2

RAP Eastern US Precipitation 6-hr Forecast



Reduced moist bias at low precip thresholds

Reduced dry bias at high precip thresholds

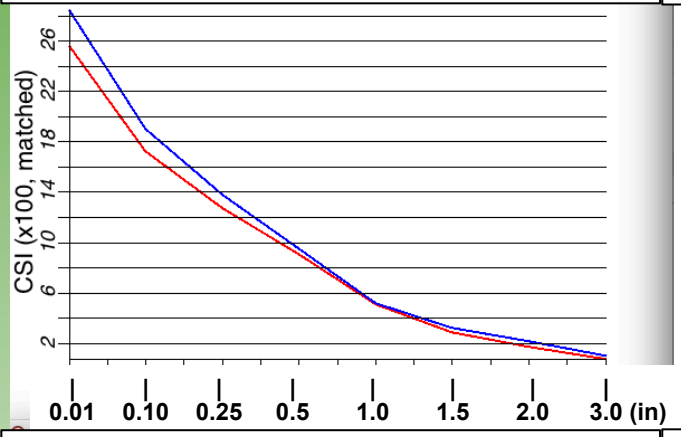
HRRRv2 Retrospective Tests: Precipitation

Eastern US
15 Jul – 15 Aug 2014

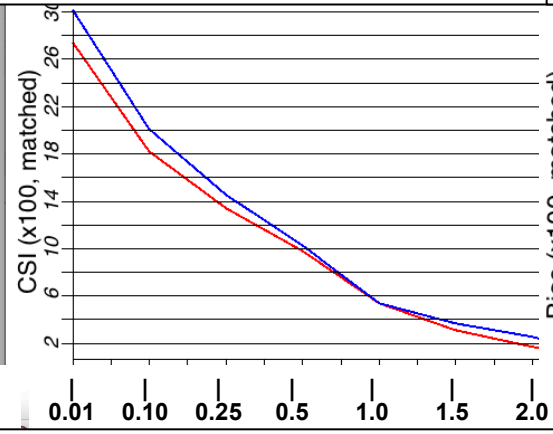
Exper HRRRv2
Real-Time HRRRv1

HRRR Eastern US Precipitation 6-hr Forecast

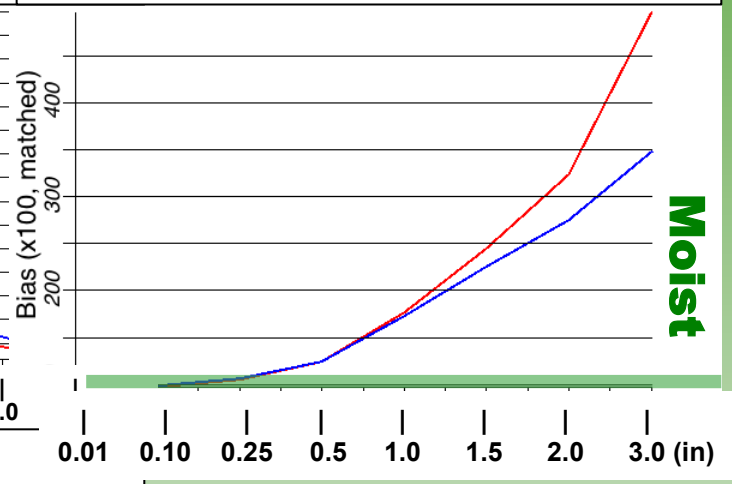
CSI 3-km



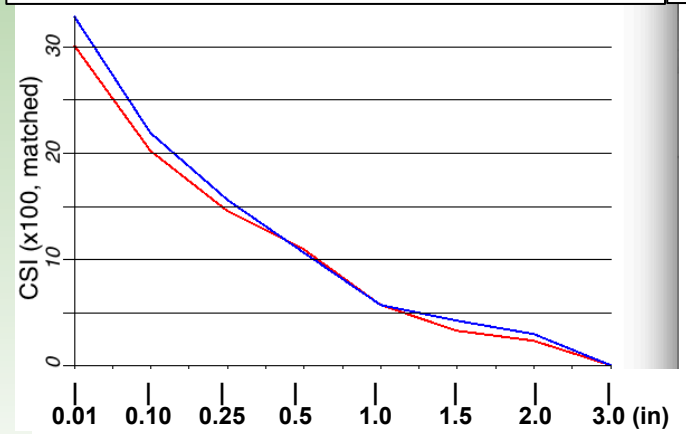
CSI 20-km



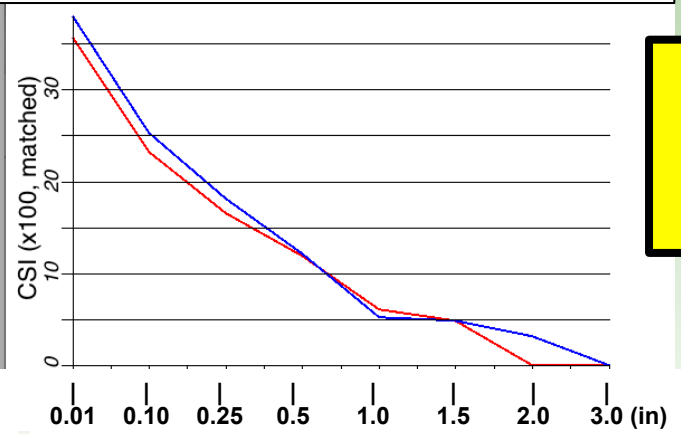
BIAS 3-km



CSI 40-km



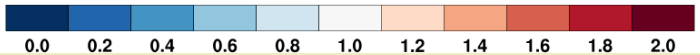
CSI 80-km



Reduced moist bias at high precip thresholds

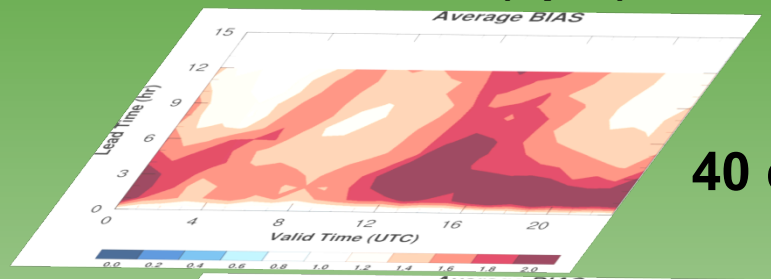
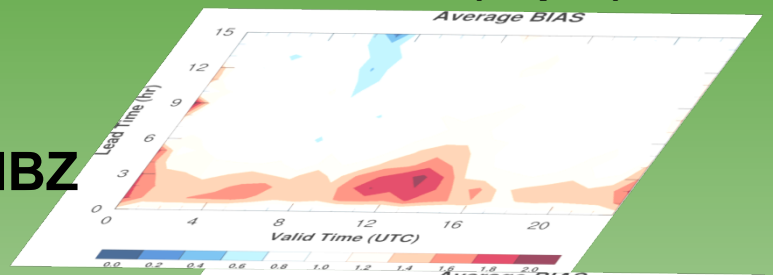
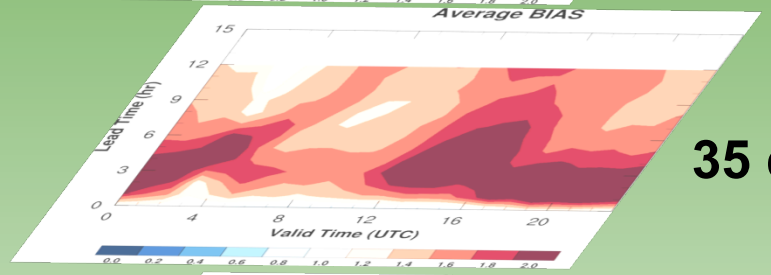
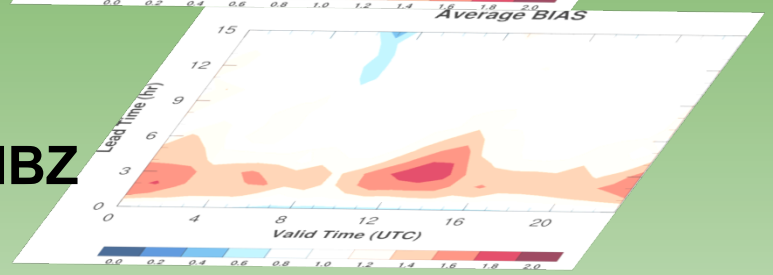
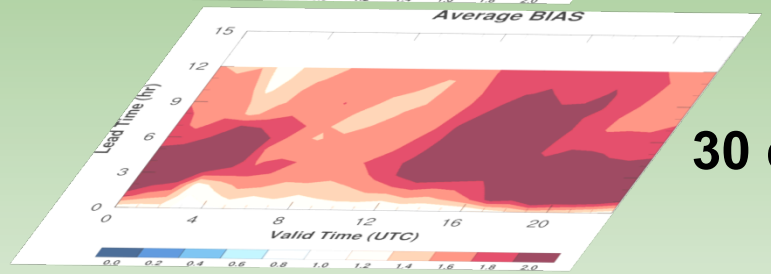
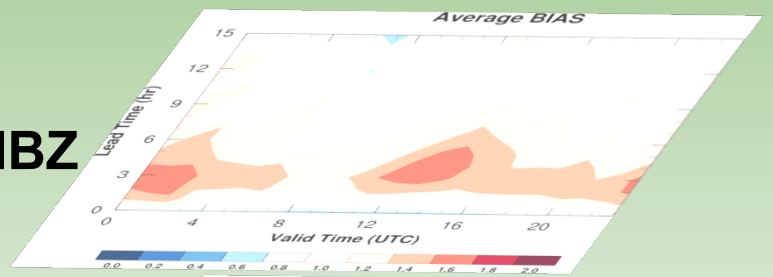
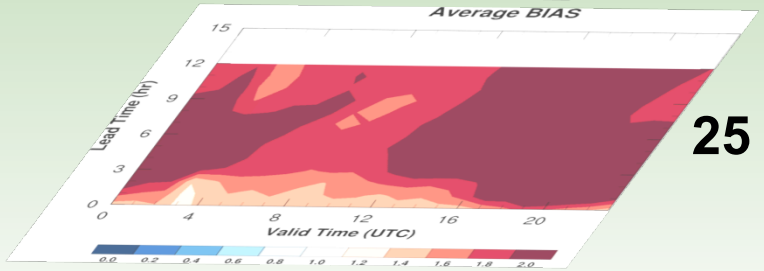
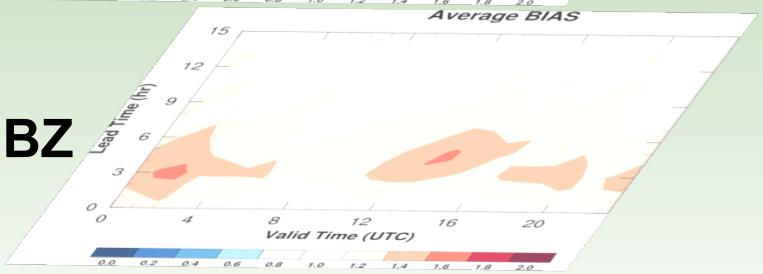
HRRRv2 Real-Time Evaluation: Reflectivity

Eastern US
May – June 2015



←Low Bias CREF High Bias→

High afternoon bias in HRRRv1 improved in HRRRv2

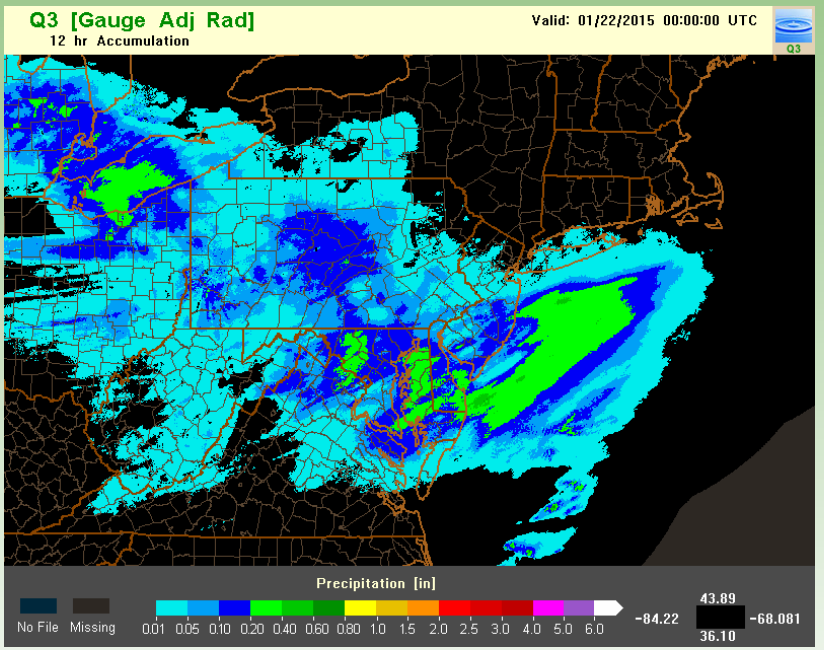
	HRRRv1 (oper)	HRRRv2 (exper)
40 dBZ		
35 dBZ		
30 dBZ		
25 dBZ		

HRRRv2 Real-Time Case Study: Winter Precipitation

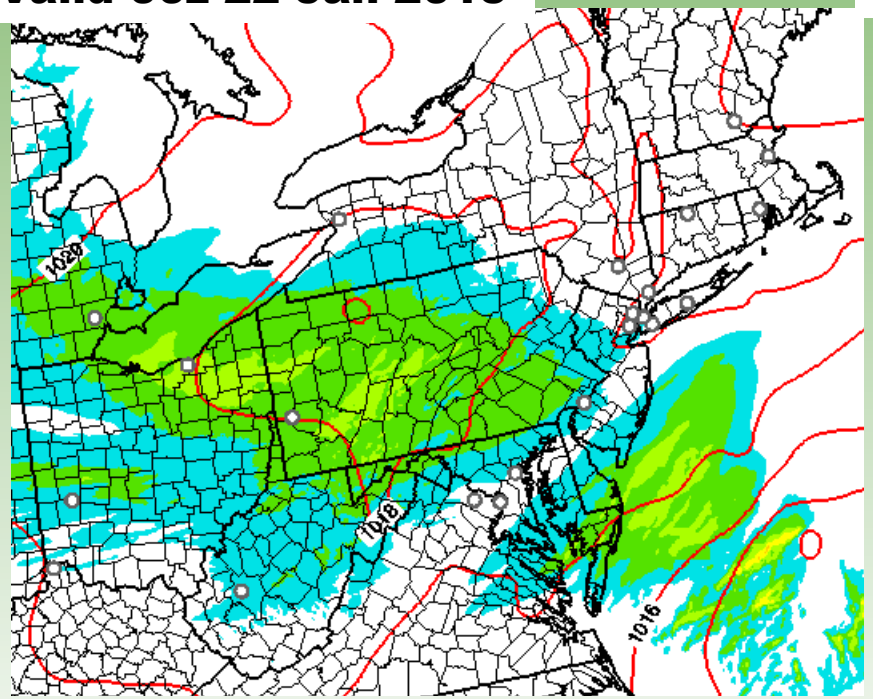
"Clipper" System
Produced 1-2" snow
D.C. Metro
21 Jan 2015

More precipitation produced in D.C. and northern suburbs

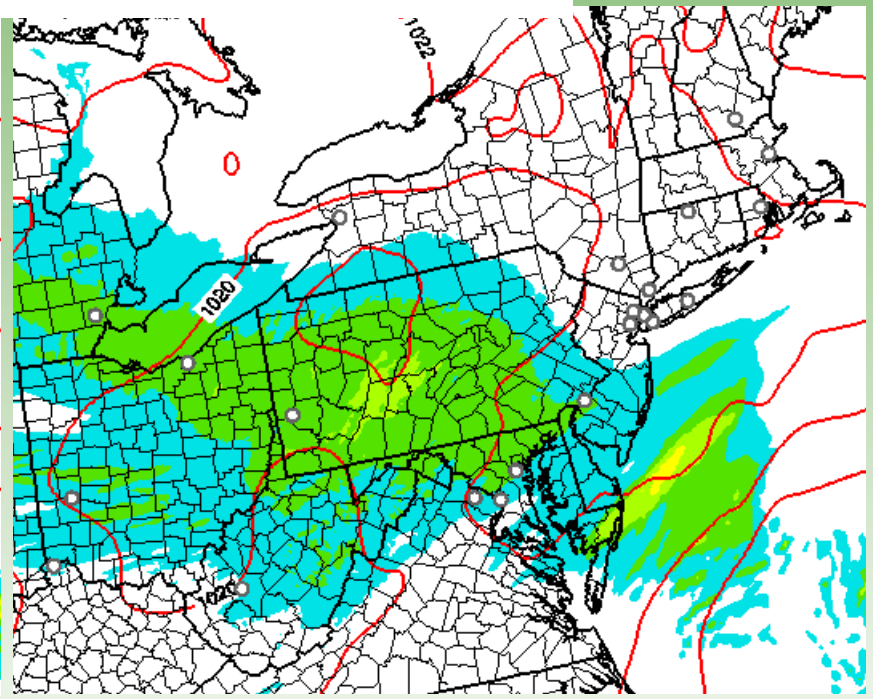
Observed 12hr Precip
Valid 00z 22 Jan 2015

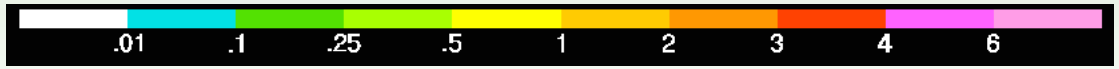


Oper HRRR 12 hr fcst
Valid 00z 22 Jan 2015



Exper HRRR 12 hr fcst
Valid 00z 22 Jan 2015

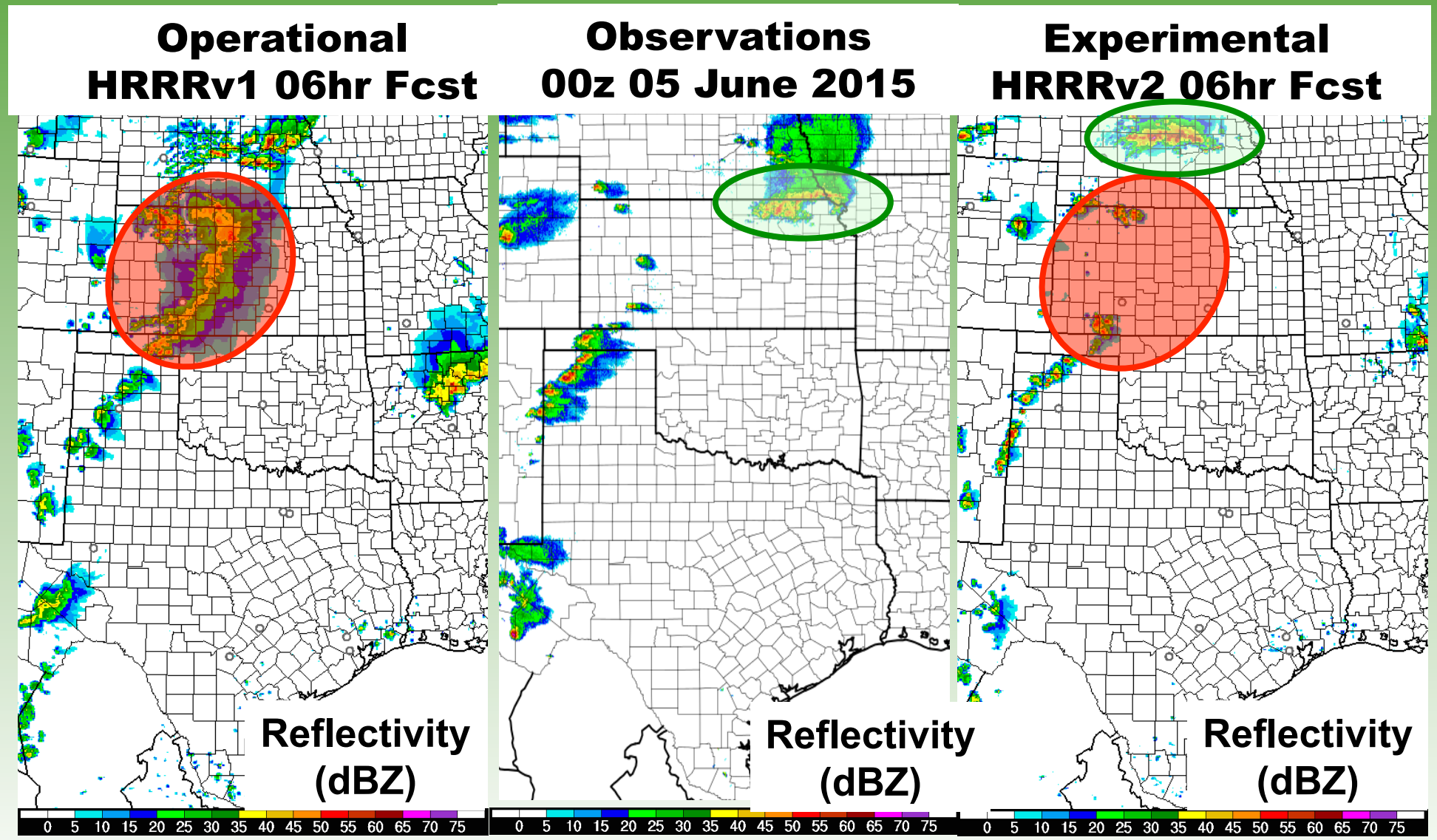




HRRRv2 Real-Time Case Study: Spring Convection

Removal of false alarm convection

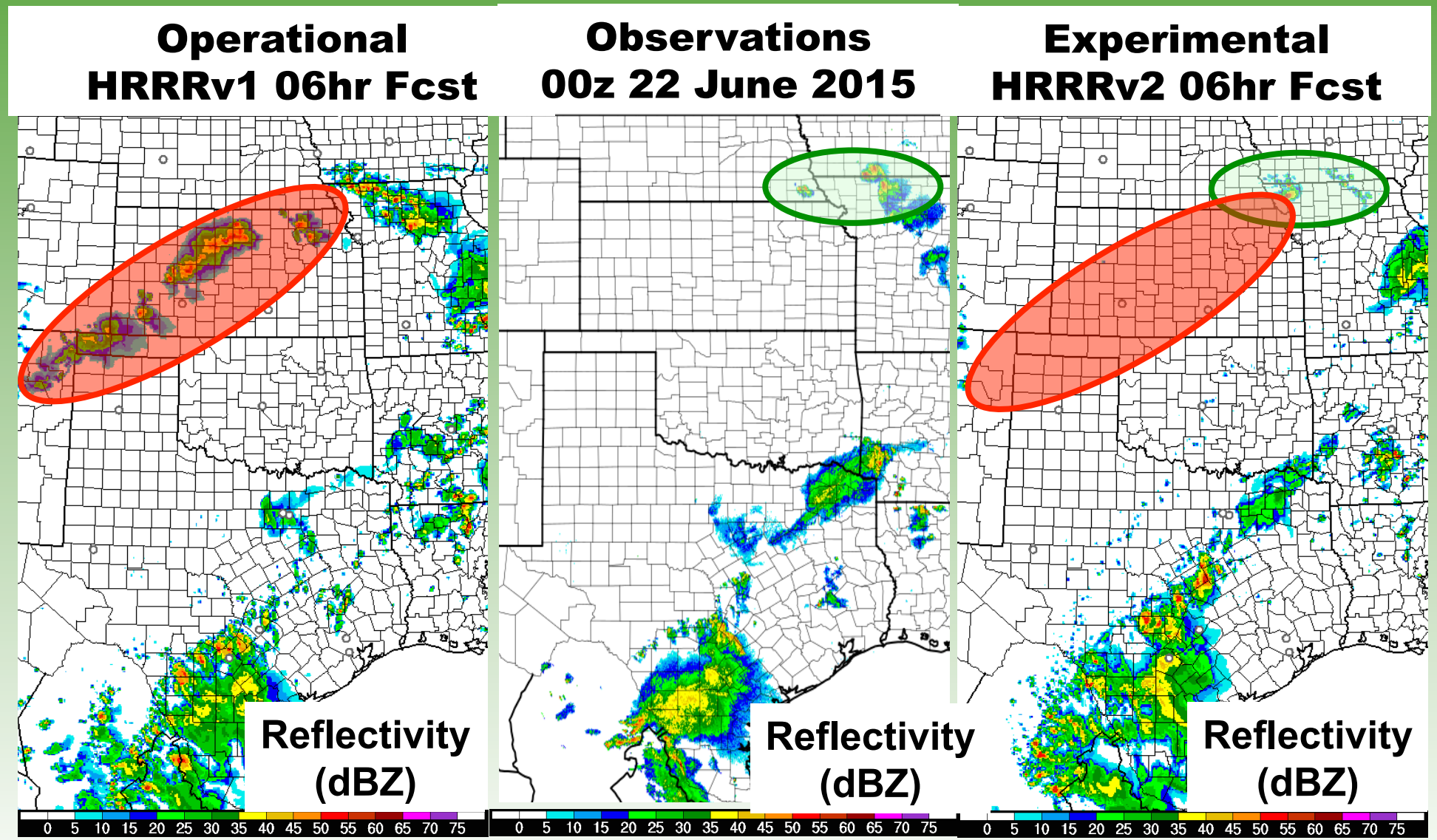
More accurate evolution of observed convection



HRRRv2 Real-Time Case Study: Summer Convection

Removal of false alarm convection

More accurate evolution of observed convection

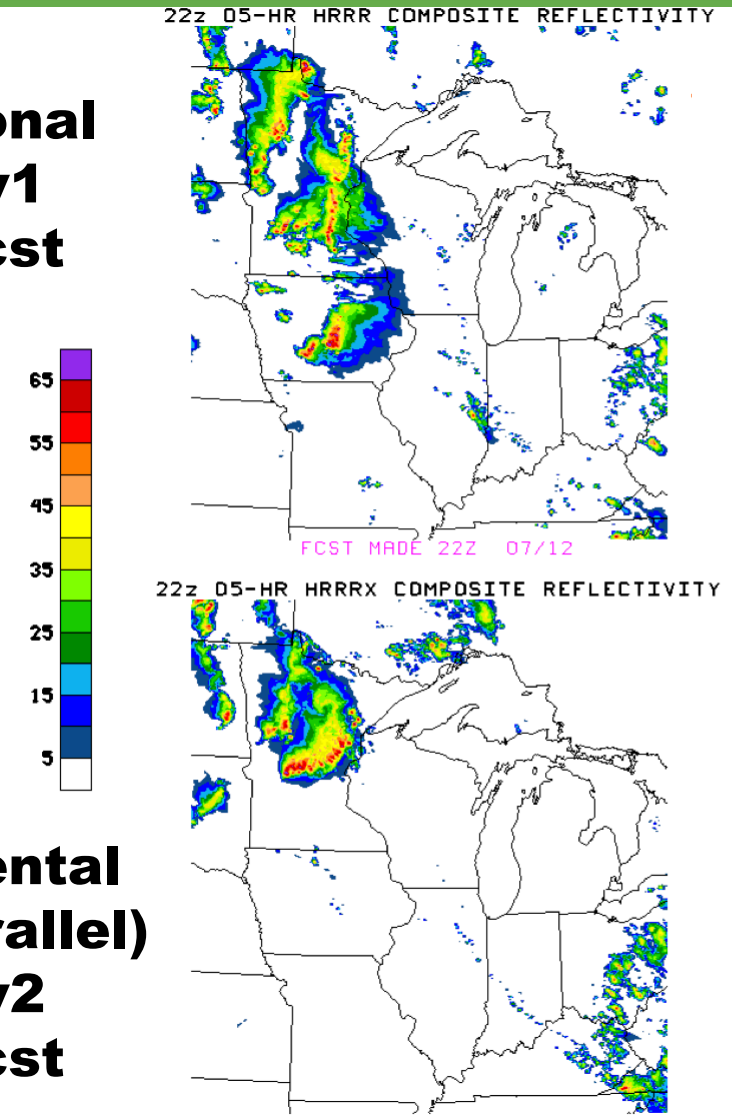


HRRRv2 Real-Time Case Study: Summer Convection

Removal of false alarm convection

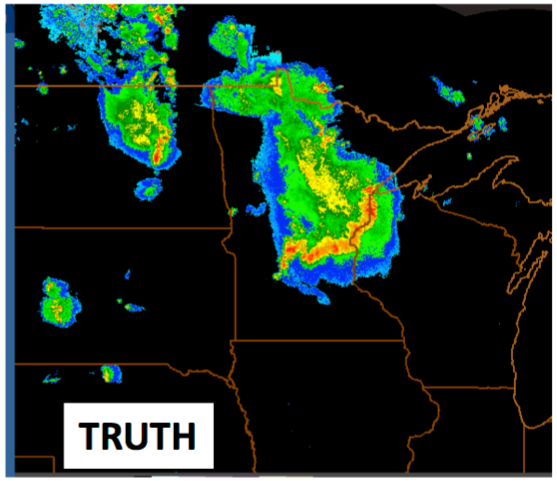
More accurate evolution of observed convection

Operational HRRRv1 05hr Fcst



Experimental (NCEP Parallel) HRRRv2 05hr Fcst

Observations 03z 13 July 2015



RAPv3/HRRRv2: New Model Forecast Fields

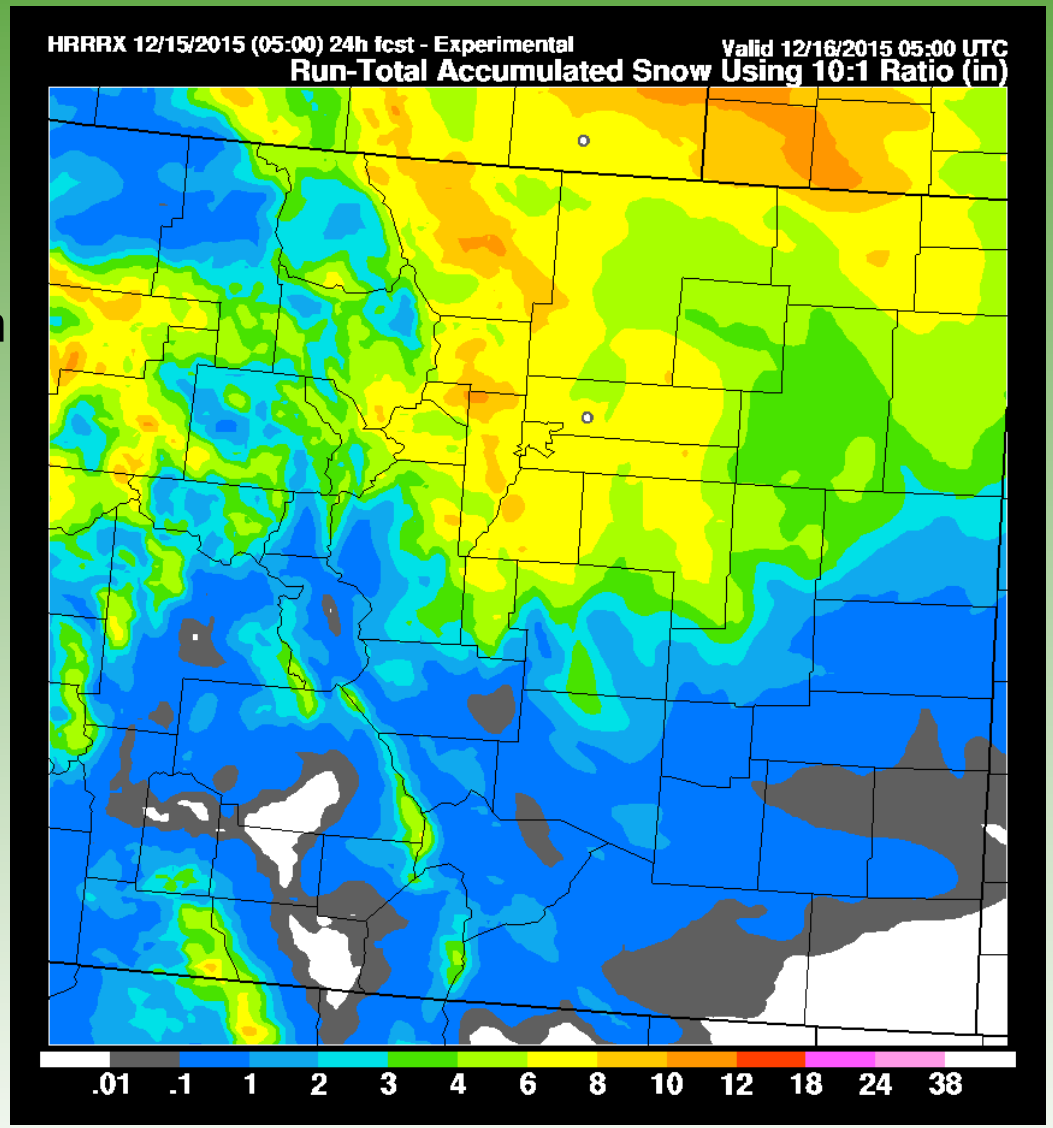
Highlights:

➢ 3-D
- Rain, cloud water and cloud ice number concentration
- Ice-friendly and water-friendly aerosol number concentration
- Cloud fraction (includes sub-grid scale cloud contributions)

➢ 2-D
- Downward direct-normal incident shortwave radiation flux
- Downward diffuse shortwave radiation flux

- Separate graupel and snow-water equivalent accumulations

- Run-total accumulated snow depth with variable-density microphysical contributions (no 10:1 assumption)
  - Deeper snow accumulations in colder regions
  - Shallower snow accumulations in warmer regions



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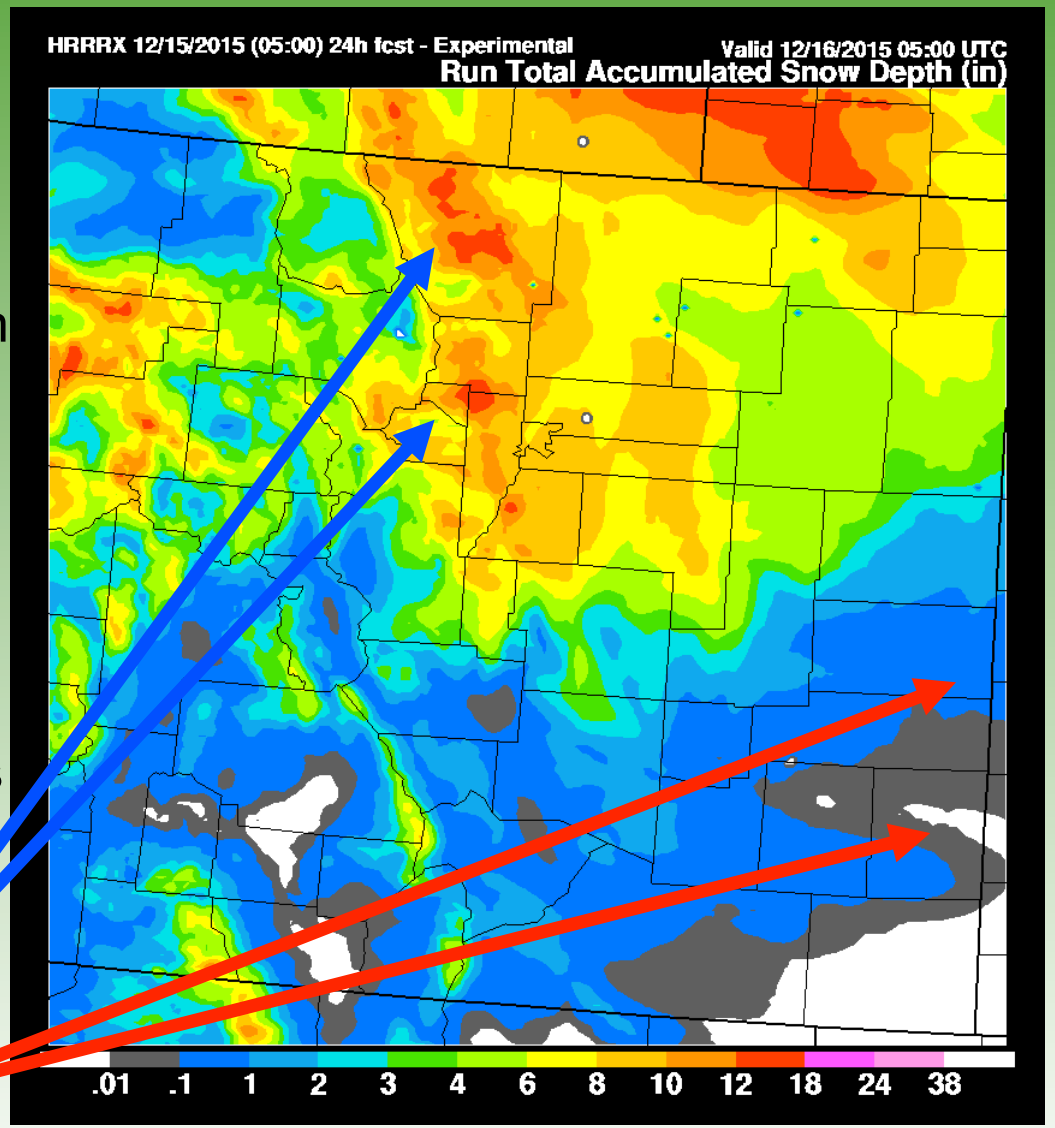
- Downward diffuse shortwave radiation flux

- Separate graupel and snow-water equivalent accumulations

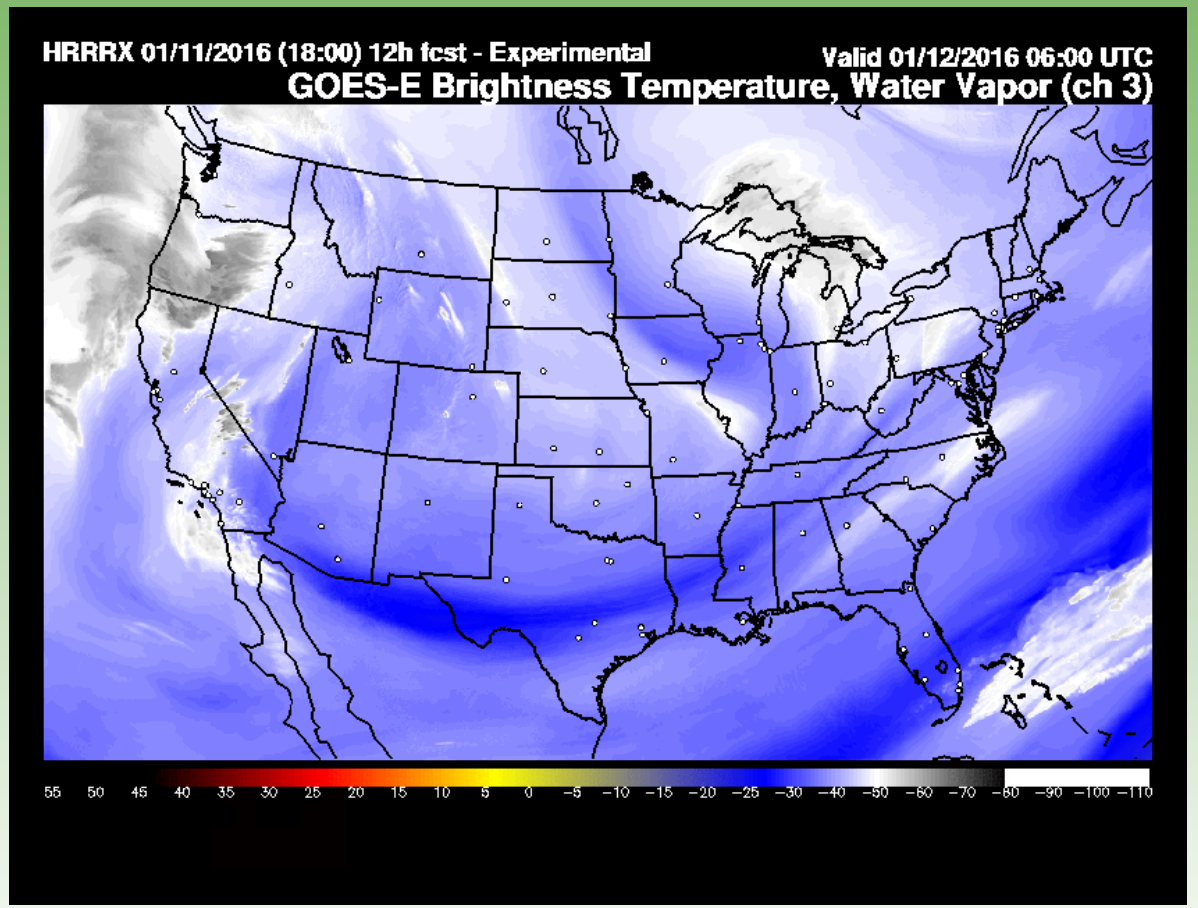
- Run-total accumulated snow depth with variable-density microphysical contributions (no 10:1 assumption)
  - Deeper snow accumulations in colder regions
  - Shallower snow accumulations in warmer regions



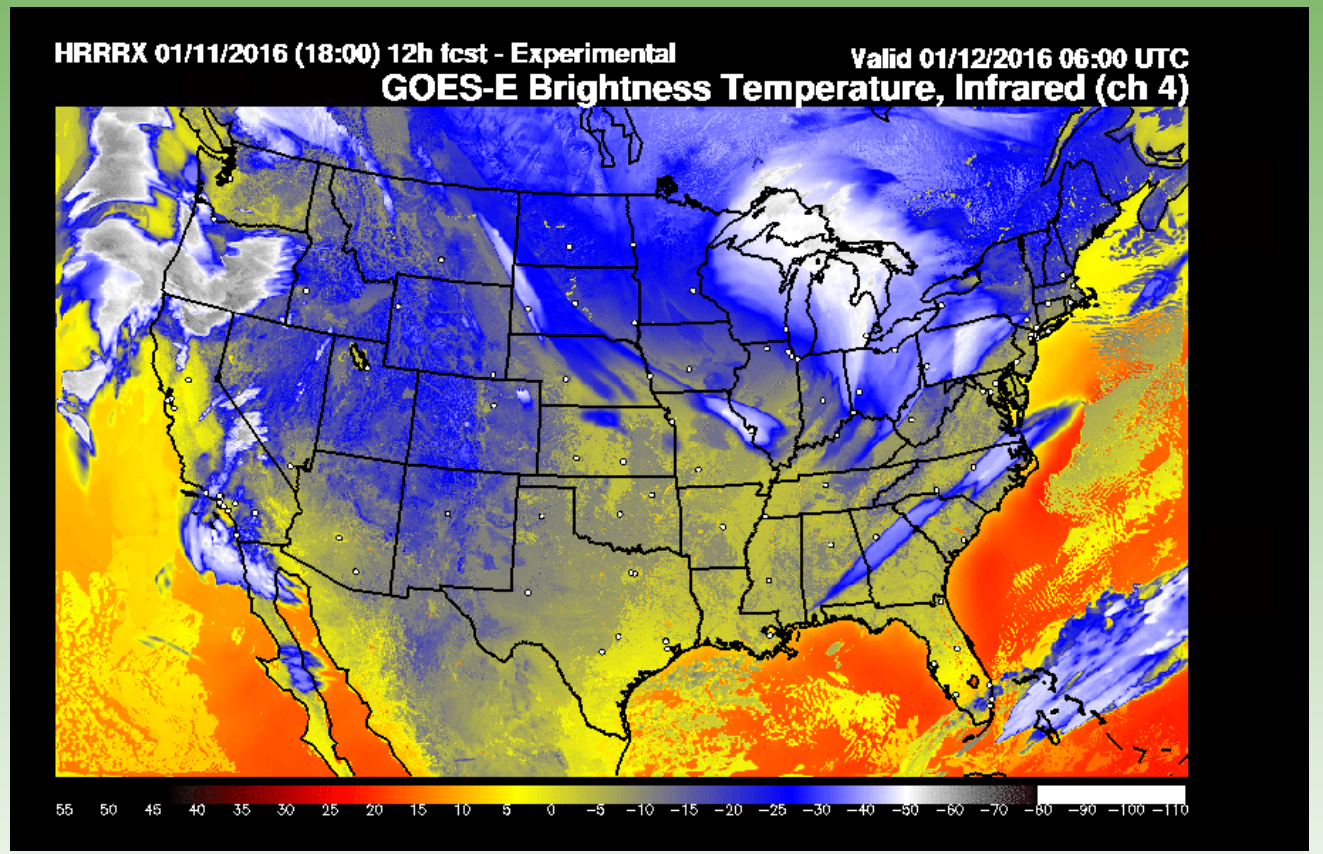
RAPv3/HRRRv2: New Model Forecast Fields

HRRRv2: Simulated Satellite Imagery (GOES-East and GOES-West)

Water Vapor



Infrared



RAPv3/HRRRv2: Forecast Performance Summary

RAPv3/HRRRv2 Enhancements
Operational Upgrade: 12 May 2016

- Winds -- Consistent RAPv3 improvement for both upper-air and surface, for all seasons
- Temperature – Reduced low-level warm bias for warm season afternoon / evening. Improved upper-level temperature forecasts
- Moisture – Reduced low-level dry bias for warm season afternoon / evening. Improved upper-level relative humidity forecast
- Precipitation – Slight improvement, reduced low thresh high bias / increased high thresh low bias, more accurate synoptic feature placement
- Convection – HRRRv2 reduces spurious convection in capped warm-sectors, permits more accurate convective evolutions

RAP/HRRR Development and Implementation Timeline

ESRL Experimental Versions	NCEP Operational Versions
➢ **RAPv3 – GSD testing in 2014-15** – **Is initializing 2015 ESRL-HRRR(v2)** – Improved PBL, LSM, cu-parm, DA – WRFv3.6.1 w/ Thompson/NCAR aerosol-aware microphysics	**May 2016**
➢ **HRRRv2 – GSD testing in 2014-15** – **Initialized by 2015 RAP (v3)** – Improved radar assimilation, hybrid assimilation, PBL/cloud physics	**May 2016**
➢ **RAPv4 – GSD testing in mid-2016** – Hourly RAP ensemble data assimilation	**Late 2017?**
➢ **HRRRv3 – GSD testing in mid-2016** – Improved 3km physics – Full 3-km hourly cycling w/radial vel – Cycling of aerosols with fire/emissions	**Late 2017?**